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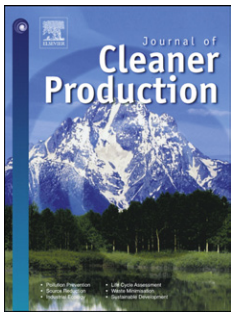

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Green as the New Lean:
How to Use Lean Practices as a Catalyst to Greening Your Supply Chain

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Abstract
The aim of this research paper is to explore and evaluate previous work focusing on the relationship and links between Lean and Green supply chain management practices. Several explanatory frameworks are explored and discussed. It is intended that evidence and insights can be developed and used: (a) to assist our understanding of where Lean practices are synergistic for Green; (b) to clarify if Green practices are synergistic for Lean; and (c) to identify opportunities for companies to use their Lean framework as a catalyst to making their processes Green. The paper provides evidence suggesting that Lean is beneficial for Green practices and the implementation of Green practices in turn also has a positive influence on existing Lean business practices.

Keywords
Green, Sustainability, Environment, Lean, Supply Chain Management

1. Introduction
Only a handful of environmental experts and researchers have so far investigated the relationship between aspects of Lean and Green practices. Starting from being claimed as '*parallel universes*' (Larson and Greenwood, 2004), they have recognised more than just an amicable co-existence. King and Lenox (2001) describe Green as '*the good public spillover of Lean'* and explain these positive side-effects in the efforts towards waste reduction and the cutting back of pollution. Bergmiller and McCright (2009a, 2009b, and 2009c) emphasise that the move towards Green manufacturing is more than just a coincidental side-effect but rather a natural extension, or natural stepping stone, as Franchetti *et al.* (2009) express it. Due to the commitment to Lean production, most firms have the natural tendency to gear towards Green practices. Generally speaking, most papers that address the connection of Lean and Green touch on the efficient use of energy (and resources) and the reduction of waste and pollution (King and Lenox, 2001; Larson and Greenwood, 2004; Linton *et al.*, 2007; Carvalho and Cruz-Machado, 2009; Bergmiller and McCright, 2009b; Tseng et al; 2009b; Mollenkopf *et al.*, 2010; Yang et al. 2011).

Thus, goals set for achieving Leanness will be a catalyst for successfully implementing Green practices and help in reaching Green goals as well (King and Lenox, 2001; Bergmiller and McCright, 2009b; Larson and Greenwood, 2004; Tseng et al. 2009a).

Carvalho and Cruz-Machado (2009) elevate this connection onto a new level and describe Lean and Green practices as a synergistic joining of environmental and operations management. In a synergy, all partners have to influence each other in a positive way, increasing the greater benefits of the relationship. A synergy is often described with the equation 1+1=3, meaning that combined practices have greater results than the sum of the separate performances. Thus, in a synergy of the Lean and Green paradigms, Lean has to be driving forward and enhancing Green practices while at the same time Green has to be synergistic for Lean.

Interestingly, existing literature shows that Green practices can help companies to become Leaner. By studying Shingo prize winners and finalists, Bergmiller and McCright (2009a) identify the correlation between Green operations and Lean results. They found that Lean companies which include Green practices achieve better Lean results than those companies which do not. In short, their findings indicate that only when both paradigms are implemented simultaneously, Lean and Green can unfold their full potential and bring greater benefits than when implemented separately. As such, researchers (Hansen *et al.*, 2004; Kleindorfer *et al.*, 2005) point out that '*while Lean practices can lead to environmental benefits, inversely environmental practices often lead to improved Lean practices'*.

Despite the combination of Lean and Green being mentioned in published articles, only few examples are available to explain how managers can integrate Green methodologies into current Lean practices. Facing resource constraints, most managers aim for a simultaneous integration of Lean and Green principles into their operations. They ask '***How can Lean practices be used as a catalyst for Greening the supply chain?***' In other words, how to generate profits in an environmental friendly way without large investments or extensive changes to the supply chain?

In light of the shortcomings of existing literature on the Lean and Green integration, this paper aims to address this gap and provide guidelines to assist managers in Greening their Lean supply chain. It aims to explore and evaluate existing literature with the objective to seek out examples on the overlap of Lean and Green supply chain management practices. In particular, this research will suggest various ways for companies to integrate Green practices in the company's Lean supply chain management environment. It is important to note that this research does not aim to provide a way for companies to paint Lean Green. It rather seeks opportunities to fit environmental considerations and tools into the context of Lean supply chain management and is intended that the information gathered from literature can be used (a) to assist our understanding of where Lean practices are synergistic for Green; (b) to clarify if Green practices are synergistic for Lean practices; and (c) to identify opportunities that Lean companies have to make their processes Green.

2. Lean and Green - Connection beyond Waste Reduction

A number of authors have investigated various aspects of Lean and Green paradigms in supply chain management. Carvalho and Cruz-Machado (2009) explore the integration

of Lean, agile, resilient and Green paradigms. They depict the causal relationships of supply chain attributes and key performance indicators (KPIs) cost, service level and lead time in a conceptual model, providing a thorough understanding of synergies and discrepancies between them. Synergies arise from the different characteristics of Lean and Green practices on the supply chain attributes of capacity surplus, integration level, inventory level, production lead time and transportation time (Carvalho and Cruz-Machado, 2009).

Mollenkopf *et al.* (2010) conduct an extensive literature review in order to examine the relationship of Green, Lean, and global supply chain strategies. They conclude that both internal as well as external factors are drivers for the integration of Lean supply chain processes and environmental practices. Lean and Green supply chain strategies coincide in their requirement for external auditing and on-going reviews, their need of efficient systems to reduce the production of undesired by-products and in their immense impact on functional processes along the supply chain. On the contrary, the authors state that it is difficult for firms to capitalise on the environmental benefits that come with Lean, implementation of environmental initiatives can be time consuming, and the alteration of technology to make processes and products more environmentally friendly requires a large up-front investment (Mollenkopf *et al.*, 2010).

Simpson and Power (2005) investigate the three main concepts of Lean manufacturing, environmental management practices, and supply relationship. The authors investigate how a tight customer-supplier relationship could influence the supplier's environmental management activities. They show that having a close relationship with suppliers is key for a company in order to guarantee sustainability of their products and services. However, the authors also admit that rising transaction costs when including environmental standards to the purchasing criteria and the difficulty of appropriately developing a set of environmental specifications and managing it effectively are very critical issues for success (Simpson and Power, 2005).

Venkat and Wakeland (2006) analysed the environmental performance of Lean supply chains using CO_2 emissions as KPI. Emissions in a supply chain are subject to the frequency and mode of transportation used, and the type and volume of inventory held at each point in the chain. Using a simulation model of a generic supply chain, the authors conclude that Lean supply chains are not necessarily Green. The emissions of a supply chain highly depend on its length and geographical expansion. A small regional supply chain would therefore almost certainly be Green due to short distances and low levels of inventory required. As the supply chain increases in length and stretches farther geographically, emissions also increase, and Lean and Green practices start to conflict (Venkat and Wakeland, 2006).

King and Lenox (2001) carried out an empirical analysis of 17,000 US companies and provide evidence that ISO 9000 adopters are more likely to adopt the Environmental Management Standard ISO 14000. Underlining the complementarities of Lean and Green practices, they recommend implementing both paradigms '*in bundles'*. Simons and Mason (2003) take the idea of combined implementation a step further. They recognise Lean's emphasis on optimising the entire supply chain from end-to-end rather than creating '*islands of improvement*' and emphasise that this should be done for the

implementation of Green practices as well. They say that Green should not just be a practice for manufacturing but should rather be incorporated already further upstream in the supply chain, i.e. in the product design phase.

In 2000, the US Environmental Protection Agency published a guide for environmental accounting. With this they take the combination of Lean and Green practices away from supply chain thinking and adopt it into organisational support practices of a firm. The '*Practical Guide for Materials Managers and Supply Chain Managers to Reduce Costs and Improve Environmental Performance'* is a four-step framework that helps detecting environmental costs. The framework shows how managers could use environmental information to make strategic financial sourcing decisions and improve financial performance along the entire supply chain.

2.1 Areas where Lean and Green cannot be combined

Despite the importance of the synergistic relationship of Lean and Green practices, there are areas where the two paradigms cannot be combined. Franchetti *et al.* (2009) state that the only real difference between Lean and Green lies in the different views these practices have of the nature of the environment. Whereas Lean practices view the environment as a valuable resource, Green practices see the environment as a constraint for designing and producing product and services. This shows the existence of a potential conflict between Lean principles and the objectives of environmentally friendly practices.

Indeed, firms may have to compromise some of their Lean practices in order to achieve environmental friendliness. Studying Lean and Green practices in the car painting process of 17 manufacturing plants, Rothenberg *et al.* (2001) show that trade-offs between both practices are inevitable. Painting cars in batches of the same colour, for example, reduces air pollutant emissions, but does stand in conflict with JIT principles. Using Lean practices which aim at eliminating any rework and working under the '*get it right the first time*' principle, manufacturers use spray paints which yield better quality and additionally are more cost effective. On the contrary, spray paints mean greater harm for the environment. Clearly, not all Lean processes, procedures and waste reduction efforts are positively related to environmental performance or pollution reduction and Lean practices alone will never be enough to address all environmental issues.

Lean practices do not necessarily reduce carbon dioxide emissions. Through the pull system with small batches and JIT delivery, Lean prescribes an increase in the replenishment frequency whereas Green practices aim at reducing transport time and replenishment frequencies (Venkat and Wakeland, 2006; Carvalho and Cruz-Machado, 2009). Transport, as the major producer of CO_2 emissions, plays an important role in pursuing Green practices. When a supply chain is long and geographically wide-spread, although it may be Lean, it is not necessarily Green due to increased amounts of CO_2 emissions from transport (Venkat and Wakeland, 2006).

Moreover, efficiency gains in light of Lean practices in the areas of inventory reduction and small batch size production, for example, may lead to greater production of waste (King and Lenox, 2001). In small batch size production, more frequent changeovers are

required. These might be carried out very fast, according to the Single Minute Exchange of Dies (SMED) principle, however, they increase the amount of cleaning (and consequently cleaning products) required and also enhance disposal of unused process material (King and Lenox, 2001).

3. Methodology

The study of the Lean paradigm as a catalyst for Green practices and vice versa has relatively little theoretical background. Until recently, insights into the Lean-Green relationship were only fragmented. The scope of this research involves a systematic review, exploring aspects of the literature and empirical evidence to identify synergies between Lean and Green concepts.

The goal of the study was to get a more detailed overview about the work that has been carried out previously, and to explore the present synergy without focusing on one particular example company of one particular industry. The objective of choosing this approach was to enable a '*helicopter view'* on how to use Lean practices as a catalyst to Greening the supply chain. Therefore, company examples were searched for, starting with industry-wide studies which covered Green topics as published by KPMG (2011a) or the Chartered Management Institute (CMI, 2009). These were identified during an open Internet search using Google. The case companies covered in this research were selected in order to give examples from a diversity of industries. The variety was chosen in order to provide the readers, who might have different backgrounds and might come from different fields, with appropriate examples for their industry and field of activity.

The review of the literature was made up of a number of stages and was designed with the scope of this study in mind. The first step was the identification of keywords through brainstorming. This was an iterative process, starting with the single words 'Lean' and 'Green', extending them to 'Lean', 'TPS', 'JIT', 'Lean Supply Chain Management', for Lean, and 'Green', 'Sustainability', and 'Green Supply Chain Management', for Green after becoming more familiar with the topic and terminology used. These keywords were first searched for individually, and the search was later extended to search strings using combinations of the words. A simple search in Google Scholar, for example, revealed 880 hits for 'Lean and Green'. The search was refined with the help of eight search engines that included ABI ProQuest (61 hits), EBSCO Business Source Premier (95 hits), Elsevier Science Direct (132 hits), Emerald (79 hits), Web of Science (20 hits), and specific operations management journal databases. The literature search was initially carried out as a subject search criteria, and, in case zero items were found, as a general text search within the databases. In the selection of papers, the limit was set to publications from 1990 to present and attention was laid on supply chain rather than highly ecological or technical papers. Once the articles which matched the search criteria were identified, the abstract was read and evaluated and a decision was made as to whether the article fit into one of the following three categories: category 'A' for being of direct relevance; category 'B' for being vaguely but not directly relevant, and category 'C' for being interesting but not relevant for this particular study. The list of 'A'-rated articles were then read and evaluated as to whether they could contribute to the study in question (Pittaway *et al.*, 2004).

4. Research Findings

The distinguishing attributes of the Lean and Green paradigm are summarised in Table 1. A comparison on purpose, focus, customers, how customer satisfaction is achieved, and the typical underlying organisational structure of each paradigm is tabulated. Then, the attention is brought to supply chain specific characteristics: the relationship with suppliers and customers, and all stages along the supply chain; from product design, raw material sourcing and manufacturing, to storage, transportation, usability, and end-of-life management. The comparison table ends with contrasting the business results and KPIs of each paradigm and listing representative waste reduction techniques and other tools that are typically employed for each paradigm.

Table 1: Comparison of Lean and Green paradigms: the distinguishing attributes

Attribute	Lean Paradigm	Green Paradigm
General		
Purpose	Maximise profits through cost reduction [a]	Reducing environmental risks and impacts while improving ecological efficiency of organisations and their partners [b; c; d]
Focus	Focus on cost reduction and increased flexibility through continuous elimination of waste or NVA across the supply chain [e; f]	Focus on sustainable development and the reduction of ecological impact of industrial activities through elimination of resource waste and pollution [a; f]
Customers	Economic customer [d] driven by costs [g]	Profit, People and the Planet (triple bottom line) [d]
Customer Satisfaction	Satisfying the customers by reducing costs and lead times [a]	Satisfying the customers by helping them to being Green [f; i; j; k]
Organisational Structure	Static organisational structure with few levels in the hierarchy [e] allowing for empowerment of employees [l]	Internal environmental management system (e.g. ISO 14000) that urges employee involvement [h; l] with environmental criteria for risk-sharing [m]
Supply Chain		
Lead Time	Shorten lead time as long as it does not increase costs [e]	Reduce transportation lead time as long as it does not increase CO_2 emissions [n]
Relationship with Suppliers and Customers	Close, collaborative, reciprocal, trusting (win-win) long-term relationships with few selected suppliers [a; e; j; n]; Demand information is spread along the supply chain [o; p]; Create a network of suppliers to build common understanding and learning about waste reduction and operational efficiency in the delivery of existing products and services [o]	Inter-organisational collaboration involving transferring or/and disseminating Green knowledge to partners [q] and customer cooperation [c] and environmental risk-sharing [a]; Integration of reverse material and information [a]
Product Design	Maximise performance and minimise cost [e]	Eco-design and Life-Cycle Assessment for evaluating

		ecological risks and impact [c; r]
Raw Material Sourcing	Supplier attributes involve low cost and high quality [e]	Green purchasing [c; o]
Manufacturing	Maintain high average utilisation rate [e]; using JIT practices, 'pulling' the goods through the system based on demand [o]	Focus on resource efficiency and waste reduction for environmental benefit and developing of remanufacturing capabilities to integrate reusable/remanufactured components [s]
Inventory	Generates high turnover and minimises inventory throughout the chain [e] in order to reduce costs and free up assets [t]	Minimise inventory by reducing redundant materials [u] to free up space [v]; Introducing reusable/ remanufactured parts in material inventory [w]
Transport	Minimise material handling during manufacturing, encourages frequent small deliveries of supplies and finished products [a]	Reduce replenishment frequency in order to reduce fuel consumption and CO_2 emissions [n]
End-of-Life	Consideration stops with sale of product; No concern for impact of product use or end-of-life recovery [w]	Considers impact of product use as well as end-of-life recovery in form of re-use or recycling [w]
Business Results		
Business Results	Quality, Cost, Delivery (QCD) [j; l], Customer Satisfaction, Profitability [l]	Quality, Cost, Delivery (QCD), Customer Satisfaction, Market Position, Reputation, Product Design, Process Waste [l]
KPI	Cost, Service Level [a]	CO_2, Service Level [a]
Dominant Costs	Physical costs [g]	Costs for future generations [x]
Tools		
Principal Tool	Value Stream Mapping: deep understanding of all the processes required to bring a product to market [aa]	Life-Cycle Assessment: deep understanding of all the processes required to bring a product to market considering product design, product use and end-of-life management [y]
Waste Reduction Techniques	Vision and strategy, Innovation, Partnerships, Operations, Support functions [l]; 7 Wastes: Elimination of waste in all operational processes, internally and externally, that arise from overproduction, waiting, transportation, inappropriate processing, defects and unnecessary inventory and motion [o]	Product Redesign, Process Redesign, Substitution, Prolong Use, Disassembly, Remanufacturing, Reduce, Consume by-products internally, Returnable Packaging, Waste Segregation, Recycling, Spreading Risks, Creating Markets, Alliances [l, z]
Tools/ Practices	VSM [aa]; Inventory minimisation, Higher resources utilisation rate, Information spreading through the network, JIT, Shorter lead times [a]	Sustainable VSM [aa]; Efficiency of resource consumption, Reduction of redundant and unnecessary materials, Waste (energy, water, raw materials and non-product

		output) minimisation, Reduction of transportation lead time, Reduction of replenishment frequency, Integration of the reverse material and information flow in the SC, Environmental risk sharing [(a)]
Legend		
Source: (a) Carvalho and Cruz-Machado (2009); (b) Carvalho and Cruz-Machado (2009) referring to Rao and Holt (2005); (c) Zhu *et al.* (2008); (d) SME (2008); (e) Vonderembse *et al.* (2006); (f) Mollenkopf *et al.* (2010); (g) Christopher and Towill (2000) referring to Mason-Jones *et al.* (2000); (h) Gordon (2001); (i) KPMG (2011a); (j) Hines *et al.* (2004); (k) Yang *et al.* (2011); (l) Bergmiller and McCright (2009b); (m) Carvalho and Cruz-Machado (2009) referring to Bowen *et al.* (2001); (n) Venkat and Wakeland (2006); (o) Cox (1999); (p) Carvalho and Cruz-Machado (2009) referring to Melton (2005); (q) Carvalho and Cruz-Machado (2009) referring to Cheng *et al.* (2008); (r) Carvalho and Cruz-Machado (2009) referring to Gottberg *et al.* (2006); (s) Sarkis (2003); (t) Nicholas (1998, pp. 75-80); (u) Carvalho and Cruz-Machado (2009) referring to Darnall *et al.* (2008); (v) Franchetti *et al.* (2009); (w) Srivastava (2007); (x) UN (1987); (y) Kainuma and Tawara (2006); (z) Melnyk *et al.* (2003); (aa) Simons and Mason (2003)		

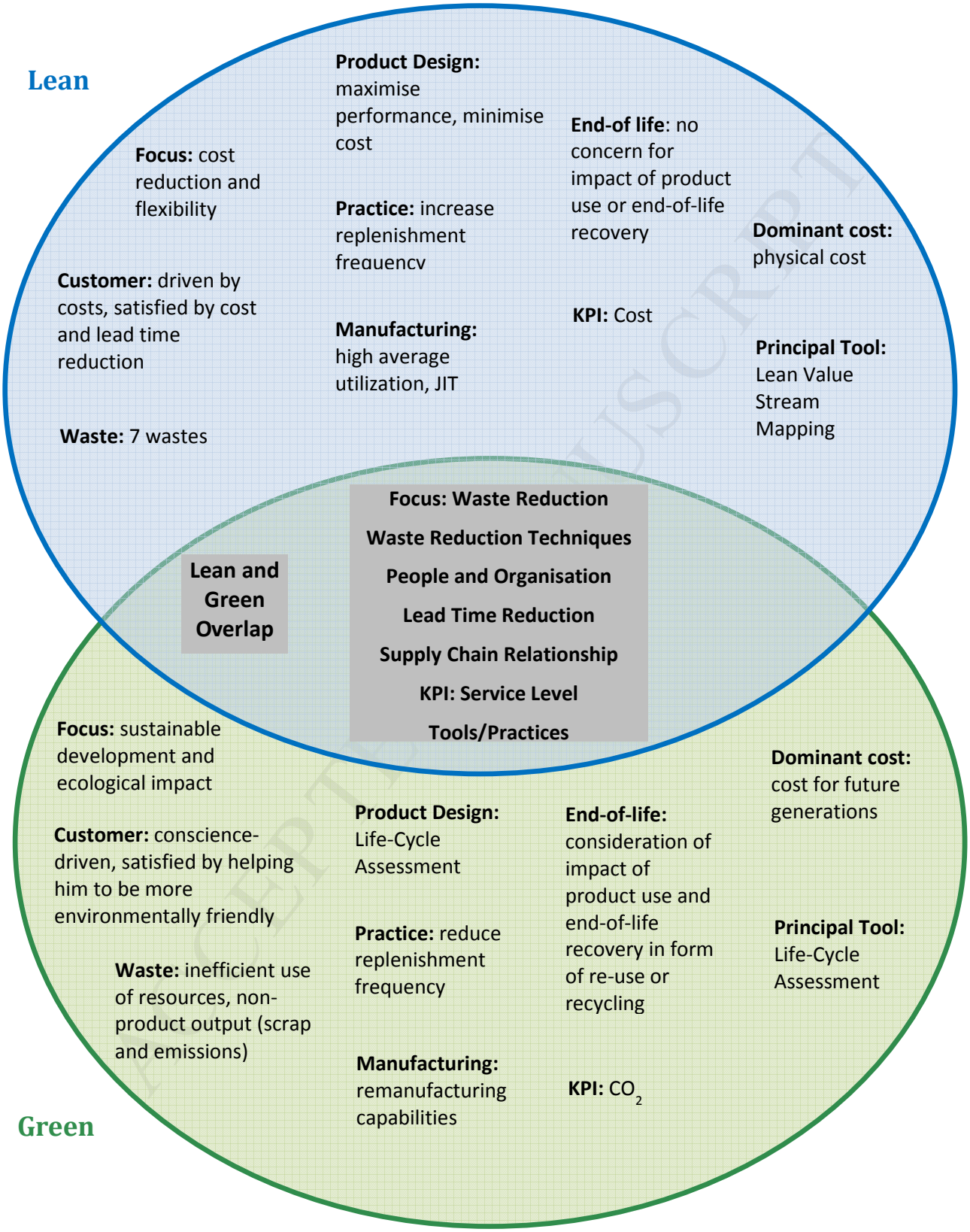
The following analysis of the research findings focuses on the connection of the two paradigms. It shows how both paradigms affect each other and where synergies (can) arise. The collected data will be presented graphically, displaying Lean, Green, and Lean and Green characteristics in overlapping circles (see Figure 1). In the first step, the attributes in which the Lean and Green paradigm already connected are shown in the overlap of the circles. The attributes outside the overlap show the discrepancy between the paradigms. The second step of the analysis specifies these differences and shows how, despite the apparent dissimilarities, the attributes are not incompatible. Attention is also being paid to those areas which require more effort in order to combine both paradigms.

4.1. Similarities

Figure 1 shows that the overlap of the Lean and Green paradigm is constituted in the following common attributes: waste and waste reduction techniques, people and organisation, lead time reduction, supply chain relationship, KPI: service level, and also certain common tools and practices they share.

The main commonality can be found in the objective of waste elimination of both paradigms. Although waste is defined in a different way by each paradigm, generally speaking both target the elimination of excess; waste in its broadest form: Lean considers the 7 wastes of manufacturing, all non-value-adding activities, as defined by Ohno (Nicholas, 1998, pp. 75-80; Vonderembse *et al.*, 2006; Mollenkopf *et al.*, 2010), whereas Green targets environmental wastes in the form of inefficient resource use or production of scrap (Carvalho and Cruz-Machado, 2009; Mollenkopf *et al.*, 2010). However, although the two paradigms have different objectives for waste elimination, they target the same type of wastes. Inventory, transportation and the production of by-products or non-product output, for example, are wastes according the Lean as well as the Green paradigm.

Figure 1: Overlap of Lean and Green Paradigms



Holding excessive inventory means additional risk to the company and detains capital (Nicholas, 1998). Additionally, inventory requires storage space that needs to be lighted and heated or chilled, which is considered waste from an environmental point of view (Franchetti *et al.*, 2009). Regarding transportation both practices aim for less transportation in order to save costs (Lean) and CO_2 output (Green) (Venkat and Wakeland, 2006; Carvalho and Cruz-Machado, 2009).

Also, they aim to reduce transportation lead times in order to create shorter supply chains that are more responsive and reduce the overall need for transportation (Simons and Mason, 2003). The Green paradigm targets the reduction of redundant and unnecessary materials in order to protect natural resources and minimise the amount of scrap produced and sent to landfill (Bergmiller and McCright, 2009a, 2009b, and 2009c; Carvalho and Cruz-Machado, 2009). Overall, adding additional Green wastes does not restrict the reduction of Lean wastes but rather enhances opportunities for further waste elimination. Combining Lean and Green paradigms in order to eliminate wastes is the solution to causing even less waste in a supply chain, which can be described as the ultimate long-term goal of a Lean - Green supply chain (LMI, 2005).

The waste reduction techniques of both paradigms are often similar, with a focus on business and production process practices (Bergmiller and McCright, 2009b). Waste reduction through a change in business practices is achieved by an adaptation of a corporate company culture (Mollenkopf *et al.*, 2010). This means changing the company's vision and integrating Lean and Green practices into support functions, such as administration and building maintenance. Both Lean and Green paradigm look into how to integrate product and process redesign in order to prolong product use, or enabling easy recycling of products as well as making processes more efficient, i.e. less wasteful (Sarkis, 2003; Bergmiller and McCright, 2009b).

In order to employ all practices and tools, both Lean and Green demand a high level of employee involvement (Gordon, 2001; Bergmiller and McCright, 2009b; Bicheno and Holweg, 2009; Mollenkopf *et al.*, 2010). Therefore, most companies often employ few hierarchical levels, encouraging the involvement of employees, and giving them responsibility (Bowen *et al.*, 2001; Gordon, 2001; Vonderembse *et al.*, 2006; Bergmiller and McCright, 2009b). This setting also simplifies the implementation of Green practices.

When it comes to supply chain relationship, both paradigms rely on close collaboration with supply chain partners. Collaboration enables information and best practices sharing across the chain and serves the goal of an integrated supply chain (Cox, 1999; Vonderembse *et al.*, 2006; Cheng *et al.*, 2008). Green practices extend the reach of the supply chain, surpassing traditional core activities (Kainuma and Tawara, 2006; Linton *et al.*, 2007), and therefore opening up opportunities for further collaboration for waste reduction and the extension of the scope of benefits.

The KPI that both practices share is the Service Level. The fabrication of products in a Green way in addition to being Lean will increase value delivery to customers. By introducing Green products, a company can distinguish itself from the competitors, target new customer groups and tap into new markets. Extending the production

practices with Green features will bring additional profits to the company without requiring much investment (Gordon, 2001).

Amongst the two paradigms, certain tools are shared. Simons and Mason (2003) introduce sustainable value stream mapping (SVSM) as an extension to traditional VSM which is used to map all processes of a supply chain. Using this approach, CO_2 emissions as an additional source of waste can easily be added.

The analysis points out that Lean serves as a catalyst for Green, meaning it facilitates a company's transformation towards Green. Implementing additional Green activities to existing Lean practices will be a comparably easy step that is not expected to require much investment of time or money. The areas in which Lean and Green practices do not connect yet, however, will require more attention and investment. These differences are analysed below.

4.2. Differences

In the following discussion, the differences of Lean and Green practices will be analysed. The research will focus on extending the overlap of the two paradigms as analysed in Figure 1. This is done in order to show that, although differences exist, the two practices are not incompatible. The analysis will explain the reason for the differences and indicate a way how the two paradigms can be connected.

Green practices are no longer optional for companies and cannot be ignored. By introducing Green practices into a Lean operating environment, companies will have to make certain trade-offs between multiple objectives that are not perfectly compatible. The differences between the Lean and Green paradigm lie in: their focus, what is considered as waste, the customer, product design and manufacturing strategy, end of product-life management, KPIs, the dominant cost, the principal tool used and certain practices as, for example, the replenishment frequency.

The focus on cost reduction and flexibility of the Lean paradigm (Vonderembse *et al.*, 2006; Mollenkopf *et al.,* 2010) does not hinder the implementation of Green practices, i.e. focus on sustainable development and are concerned about the ecological impact of operations (Carvalho and Cruz-Machado, 2009; Mollenkopf *et al.*, 2010), and vice versa. The business environment created using Lean practices can rather be described as the perfect background for implementing Green practices. Research has shown that a Lean environment, to a certain extent, is Green through the mutual focus on waste elimination (Bergmiller and McCright, 2009b). In an environment where minimising the production of waste already is common practice, waste reduction for environmental purposes can be executed with greatest results. Green practices help with further saving costs through the efficient use of resources and the reduction of redundant and unnecessary materials (Sarkis, 2003; Carvalho and Cruz-Machado, 2009). As mentioned before, this also shows that, although both paradigms target different forms of wastes, these can be combined. Green wastes can be seen as an extension to Lean wastes, and, in the effort to reducing Lean wastes, Green wastes can be incorporated and simultaneously reduced (Hansen *et al.*, 2004; Kleindorfer *et al.*, 2005; Bergmiller and McCright, 2009b; Franchetti *et al.*, 2009).

The Lean and Green paradigms are designed to target a different type of customer. The Lean customer is driven and satisfied by achieving cost and lead time reduction (Mason-Jones *et al.,* 2000; Carvalho and Cruz-Machado, 2009), whereas the Green customers are driven by their Green belief and satisfied when the products purchased help them being more environmentally friendly (Hines *et al.,* 2004; Mollenkopf *et al.*, 2010; KPMG, 2011a; Yang *et al.*, 2011). The cost-conscious customer will not criticise the integration of Green practices as long as implementing Green positively influences the cost-benefit balance. The Green customers, in turn, would not mind paying less for their products, as long as they are manufactured with environmentally sound principles. Both paradigms can thus be combined, and since the customer demand for environmentally friendly products is steadily increasing and Green practices are to be converted into compulsory business practice, companies are advised to implementing Green principles as soon as possible (Simons and Mason, 2003; Linton *et al.,* 2007).

For product design, Lean practices focus on performance maximisation and cost minimisation. While Green practices apply life-cycle assessment (LCA) in order to design the products so that every step in the product life-cycle is optimised from an environmental point of view (Kainuma and Tawara, 2006). Adopting LCA in the design phase will enable managers to build products that require less manufacturing steps, produce less by-products, build up less purpose-specific inventory through the use of universal product modules, require less packaging or space in storage or transportation, and deliver less scrap through considering remanufacturing possibilities (Simons and Mason, 2003). This illustrates that Green product design practices also fulfil the focus of the Lean paradigm.

The practices with regards to replenishment frequency are the main point of conflict of Lean and Green practices. In a Lean environment, the replenishment frequency of raw material or semi-finished product output is high since Lean is working according to JIT principles and only very little inventory is maintained (Cox, 1999; Vonderembse *et al.,* 2006; Bergmiller and McCright, 2009b). However, frequent replenishment results in an increase of transportation which increases CO_2 emissions, contradicting the CO_2 reduction principles of Green practices (Venkat and Wakeland, 2006). In the effort to making Lean Green, companies have to find ways to minimise the harm to the environment of these practices. This can be done by, for example, selecting suppliers of the same geographic area that could share truckloads when delivering or, when delivering small amounts, managing the routes in order to supply multiple customers in the same area on one delivery route. Ultimately, both practices aim for a reduction of the amount of transportation lead time which makes the practices not incompatible, but an area where trade-offs have to be made.

Through the introduction of Green practices into a Lean operating environment, the scope of the supply chain will be extended (Kainuma and Tawara, 2006). The new supply chain will range from the product design phase to end of product-life management. This includes introducing a reverse logistics cycle that manages packaging as well as returns of defective or discarded products (Cox, 1999; Kauffeld *et al.*, 2009).

With regards to the dominant cost of the two paradigms, Lean can be measured in monetary units (Mason-Jones *et al.*, 2000). However, for Green practices it is still difficult to express the cost for future generations in economic terms (UN, 1987). The establishment of regulations and standards will help to translate Green costs into financial terms which is essential for benchmarking possibilities and guarantee comparability of Green measures across the supply chain and in different industries.

The analysis of the differences shows the areas in which Lean and Green supply chain practices do not connect yet. However, it is also recognised that for these attributes it is also not impossible to introduce Green practices into a Lean operating environment. Lean still serves as a catalyst for the implementation of Green. Following the analysis of similarities and differences, the following synthesis discussion shows how the attributes of Lean and Green can be combined and how Lean can be made Green and vice versa.

4.3. Synthesis

The synthesis discusses how to get the best out of the combination of Lean and Green supply chain management practices. It will show '*Which opportunities do Lean companies have to make their processes Green?'* Also, it will provide an answer to another guiding question i.e. how companies can extend their existing business practices and use easy do-it-yourself measures in order to make their organisations more environmentally friendly.

Green, in parts, comes as a natural extension to Lean as Lean practices are Green without the explicit intention to being Green (Bergmiller and McCright, 2009c). It is also proven that Lean manufacturers are Greener than non-Lean companies (King and Lenox, 2001). But since Green practices are not the focal point of many companies, the potential to maximise Green gains with the implementation of a simple Green framework is great. Therefore, it is essential to integrate both strategies and offer these simultaneously to fully exploit the synergistic effect.

The major point of conflict between the Lean and Green paradigms are CO_2 emissions in the supply chain. In this area the two paradigms cannot just be combined. The establishment of trade-offs between Lean and Green principles and aims is essential here. A way for Lean supply chains to minimise emissions is by using more efficient transport modes, such as heavy-duty trucks and sharing trucks with other product lines and companies in order to use their full potential (Venkat and Wakeland, 2006). Thus, in making Lean Green, it is necessary to use the correct window of implementation. In order to harvest the best possible results, it is advisable to make the implementation a simultaneous process and taking care of Green while implementing Lean.

For a synergistic relationship, not only does the Lean environment have to be beneficial for the implementation of Green practices, but also do Green practices have to positively influence Lean practices. According to Larson and Greenwood (2004), environmentally sensitive processes are difficult to Lean. While Boeing achieved a 30 to 70 per cent of resource productivity improvement with the implementation of Lean practices, processes such as painting, metal finishing, chemical treatment, and heat treatment did not reach comparable gains (Larson and Greenwood, 2004). Nevertheless, a modification of the proposed Lean efforts can be developed in order to

harvest environmental benefits. Applying major Lean principles can help Green practices to being more effective by exposing hidden Green wastes and eliminating them (Womack and Jones, 2003).

5. Conclusion

Driven by current climate change discussions, many companies find themselves facing increased pressure from customers to do business in an environmentally responsible manner (Simons and Mason, 2003). For examples, the Japanese printer manufacturer Kyocera designs printers that cost less to use and have fewer parts to replace (Gordon, 2001), Boeing reduces the amount of protective cardboard and bubble wrapping used for storage and material handling of its 747 wings (Franchetti *et al.*, 2009), Compaq designs its headquarters in Houston, Texas with skylights to reduce electricity use (Gordon, 2001), the United Kingdom's (UK) Royal Mail as well as UPS operate a more sustainable alternative fuel vehicle fleet (CMI, 2009; KPMG, 2011a), Sony Corporation recycles sludge to make cement (Gordon, 2001), and crisp manufacturer Walkers UK puts a policy in place under which the company engages in reusing and recycling activities so that ultimately zero waste is sent to landfill (PepsiCo, 2011). These cases are only a few examples of Green initiatives around the world. Many senior executives realise the challenges in rethinking their company's approach towards environmental friendliness. The hesitation towards the implementation of Green practices is fuelled by the fact that there is confusion about what Green actually is and that there are only very few independent models, regulations or best practices in place that support the implementation (Bergmiller and McCright, 2009a).

The overall aim of this research is to identify potential areas in which companies can integrate Green into current business practices. To determine the best Lean and Green integration, it is necessary to understand the distinguishing attributes of the two paradigms. The overlap of Lean and Green paradigm is constituted in the following common attributes: waste and waste reduction techniques, people and organisation, lead time reduction, supply chain relationship, KPI: service level and they also share common tools and practices. The applied literature analysis identifies that Lean not only serves as a catalyst but is also synergistic for Green. This means that Lean is beneficial for Green practices and the implementation of Green practices in turn also has positive influence on existing business practices.

The differences of the Lean and Green paradigm lie in: their focus, what is considered as waste, the customer, product design and manufacturing strategy, end of product-life management, KPIs, the dominant cost, the principal tool used and certain practices as, for example, the replenishment frequency. The analysis of the differences shows the areas in which Lean and Green supply chain practices do not connect yet. However, it is also recognised that for these attributes it is also not impossible to combine Lean and Green practices.

The research findings indicate that a Lean environment serves as a catalyst to facilitate Green implementation. The integration of Lean and Green practices will bring benefits to companies and introducing Green as the new Lean is no longer a strong and unsupported statement. It is rather undeniable that the ultimate Lean will be Green.

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